DISTRIBUTED SIMULATION AND TEST AND EVALUATION: A MIDTERM REPORT ON THE UTILITY OF ADVANCED DISTRIBUTED SIMULATION TO TEST AND EVALUATION

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Abstract

The Joint Advanced Distributed Simulation Joint Test Force (JADS JTF) is chartered by the U.S. Office of the Secretary of Defense (OSD) to determine the utility of advanced distributed simulation (ADS) for both developmental and operational test and evaluation (DT&E and OT&E). The program is at its midpoint, and this paper is designed to provide a progress report on the lessons learned to date on the use of ADS in test and evaluation (T&E).

The paper opens with a brief overview of ADS technology and then a short description of the JADS Joint Test and Evaluation (JT&E) program. Third, the main portion of the paper will discuss the results and lessons learned during the ADS-enhanced testing conducted throughout the first major phases of the JADS JT&E program. Fourth, the JADS study on the linking of electronic warfare (EW) test facilities, the Threat Systems Linking Architecture (TSLA) Study, is briefly described. Finally, other considerations will be offered for the T&E professional interested in whether ADS might be a suitable test tool.

The material in this paper fuses material from other JADS documents prepared by many members of the JADS JTF. Readers are encouraged seek more information JADS has compiled either via the address above or their web site (http://www.jads.abq.com).

Overview of ADS (Ref. 1)

Since the mid-1980s, rapidly evolving information systems technology has been put to work in support of U.S. Department of Defense

(DoD) needs. Early efforts were conducted jointly by the Defense Advanced Research Projects Agency and the U.S. Army. This early project was named Simulation Network (SIMNET), and it was sharply focused on training applications. Conceptually, the project was directed toward linking training devices (simulators) with human operators in the loop at distributed sites in a common virtual environment in near real time. SIMNET evolved to distributed interactive simulation (DIS), a technology implementation which is more flexible and far reaching. Formal industry standards have been established for DIS. In turn, DIS is giving way to high level architecture (HLA), a technical approach championed by the U.S. Defense Modeling and Simulation Office.

JADS uses a more generic term for the technology – ADS. This is defined as the technology and procedures that provide a time and space coherent, interactive synthetic environment through geographically distributed and potentially dissimilar situations. Any combination of live, virtual, or constructive simulation of people and/or equipment can be used. ADS is the concept; DIS and HLA are applications of ADS.

Overview of JADS JT&E

Background (Ref. 1)

Because of widespread interest in using ADS technology to support T&E, the JADS JT&E program was nominated for feasibility study in 1993. The nomination was motivated by the T&E community's concern about long-standing test constraints and limitations, and the potential utility of ADS for relieving some of those constraints and limitations. However, there was widespread skepticism that ADS might not be able to deliver high-quality data demanded by the T&E community. The Services concurred with the need for a rigorous examination of ADS utility to testing, and OSD's Director of Test, System Engineering and Evaluation chartered JADS as a full joint test program.

JADS JT&E Charter (Ref. 2)

The basic JADS JT&E program was chartered in October 1994 to investigate the utility of ADS for both DT&E and OT&E. More specifically, JADS is to investigate the present utility of ADS, to identify critical constraints in using the technology, to develop the methodologies in using ADS in various T&E applications, and to provide growth requirements for ADS so that as it matures it better meets the needs of the T&E community.

At the time of chartering, OSD tasked JADS to investigate the possibility of specifically examining ADS utility to EW T&E. This additional facet of the program was subsequently chartered in August 1996 (Ref. 3).

Test Approach

To accomplish this charter, JADS is conducting three series of ADS-enhanced tests in widely different areas to determine the utility of ADS. Representative "systems under test" are used, ones that have already undergone testing and have been fielded. Significant system performance data is available then for comparison with the data obtained in the tests introducing ADS as a methodology. The three specific test programs are the System Integration Test (SIT) utilizing two air-to-air missiles (AIM-9M Sidewinder and AIM-120 Advanced Medium Range Air-to-Air Missile (AMRAAM)); the End-to-End Test (ETE) using the Joint Surveillance Target Attack Radar System (Joint STARS) as a representative command, control, communications, computer, intelligence, surveillance and reconnaissance (C4ISR) system; and the Electronic Warfare (EW) Test, utilizing the ALQ-131 self-protection jammer (SPJ).

System Integration Test (Ref. 4)

SIT evaluated the utility of using ADS to support cost-effective testing of an integrated missile weapon/launch aircraft system in an operationally realistic scenario. The purpose of SIT also included the evaluation of the capability of the JADS Test Control and Analysis Center (TCAC) to control a distributed test of this type and to remotely monitor and analyze test results.

SIT consisted of two phases, each of which culminated in fully linked missions. The missions simulated a single shooter aircraft launching an air-to-air missile against a single target aircraft. In the Linked Simulators Phase (LSP), the shooter, target, and missile were all represented by hardware-in-the-loop (HWIL) laboratories. LSP testing was completed in November 1996. In the Live Fly Phase (LFP), the shooter and target were represented by live aircraft and the missile by a HWIL laboratory. LFP testing was completed in October 1997.

Linked Simulators Phase. The LSP test concept was to replicate a previous AIM-9M-8/9 live fire profile in an ADS configuration and compare missile results for the LSP trials to those from the live fire test. The LSP test configuration is shown in Figure 1.

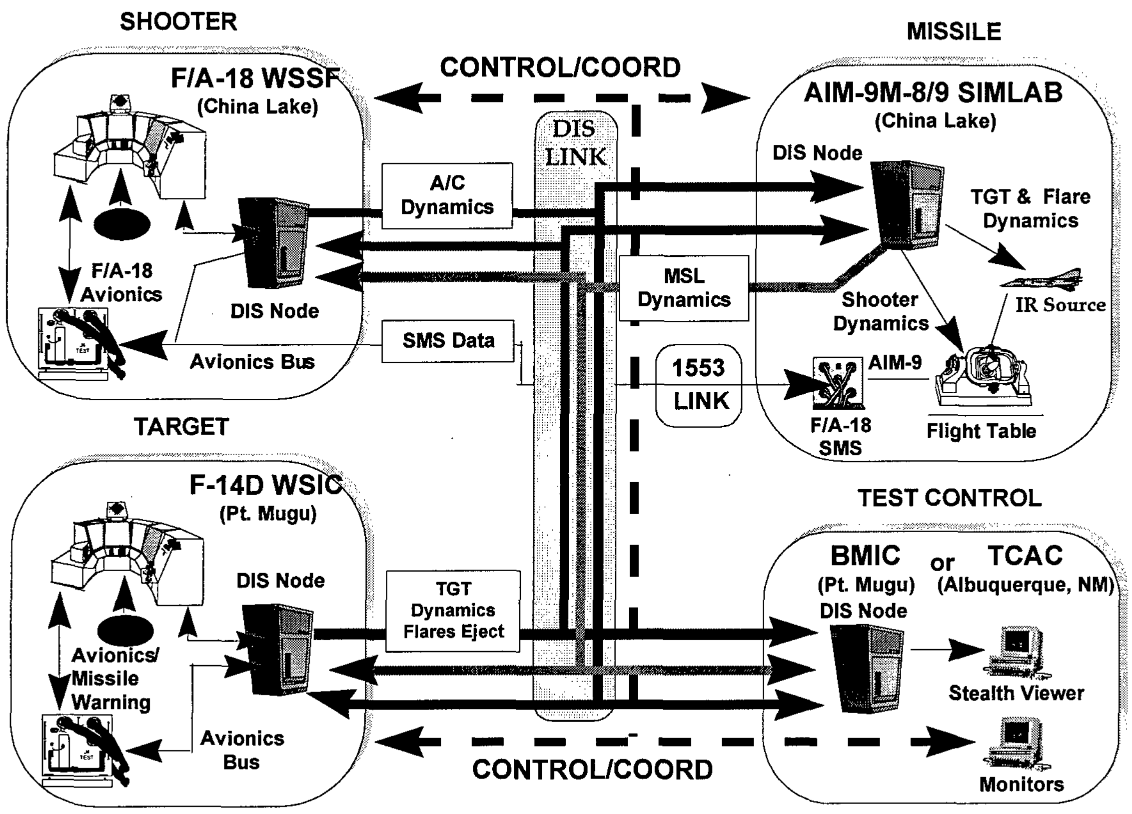

Figure 1. Linked Simulator Phase Configuration

The F/A-18 Weapon System Support Facility (WSSF) at China Lake, California, and the F-14D Weapon System Integration Center (WSIC) at Point Mugu, California, were the shooter and target, respectively. The shooter "fired" the AIM-9 in the Simulation Laboratory (SIMLAB) HWIL facility at the target which could respond with countermeasures. Runs were controlled from a test control center which ensured all nodes were ready for each run, issued start/stop directions, and processed data packets for real-time analysis of system performance. Test control was exercised from the Battle Management Interoperability Center (BMIC) at Point Mugu while the JADS Joint Test Force was physically relocating. Control switched to the JADS TCAC in Albuquerque, New Mexico after the move was complete.

Live Fly Phase. The LFP test concept was to replicate previous AMRAAM live fire profiles in an ADS configuration and compare missile results from the LFP trials to those from the live fire tests. In the LFP, ADS techniques were used to link two live F-16 aircraft (flying on the Gulf Test Range at Eglin Air Force Base, Florida) representing the shooter and target to an AMRAAM HWIL laboratory (also at Eglin) representing the missile. This configuration allowed data from live sources to drive the HWIL laboratory for more realistic missile results and is shown in Figure 2.

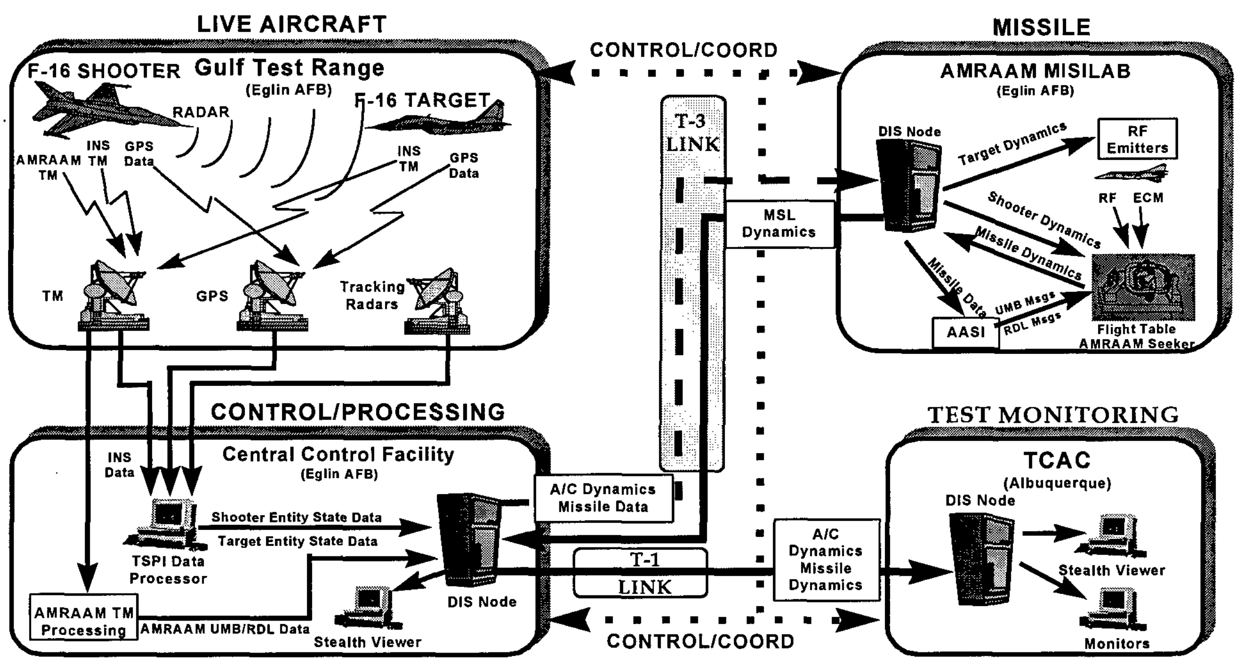

Figure 2. Live Fly Phase Configuration

Global positioning system (GPS) and telemetry (TM) data were downlinked from the aircraft and passed to the Central Control Facility (CCF) at Eglin. GPS, inertial navigation system (INS), and tracking radar data for each aircraft were combined by the TSPI (time-space-position information) Data Processor (TDP) in the CCF to produce optimal entity state solutions. The aircraft entity

state data were transformed into DIS protocol data units (PDUs) and transferred to the AMRAAM HWIL simulation at the Missile Simulation Laboratory (MISILAB) over a T3 link.

The shooter aircraft "fired" the AMRAAM in the MISILAB at the target and provided data link updates of the target position and velocity to the missile during its flyout. The AMRAAM seeker was mounted on a flight table and responded to radio frequency (RF) sources in the MISILAB which simulated the seeker return from the target, the relative motions of the target and the missile, and electronic countermeasures (ECM). A link between the CCF and the JADS TCAC allowed JADS personnel to monitor and record the simulated intercepts.

End-to-End Test

The ETE uses distributed simulations to assemble an enhanced environment to be used for testing command, control, communications and computer (C4I) systems. The object is to determine if ADS can provide a complete, robust set of interfaces from sensor to weapon system including the additional intermediate nodes that would be found in a tactical engagement. The test traces a thread of the battlefield process from target detection to target assignment and engagement at corps level using ADS. Figure 3 illustrates the basic test architecture.

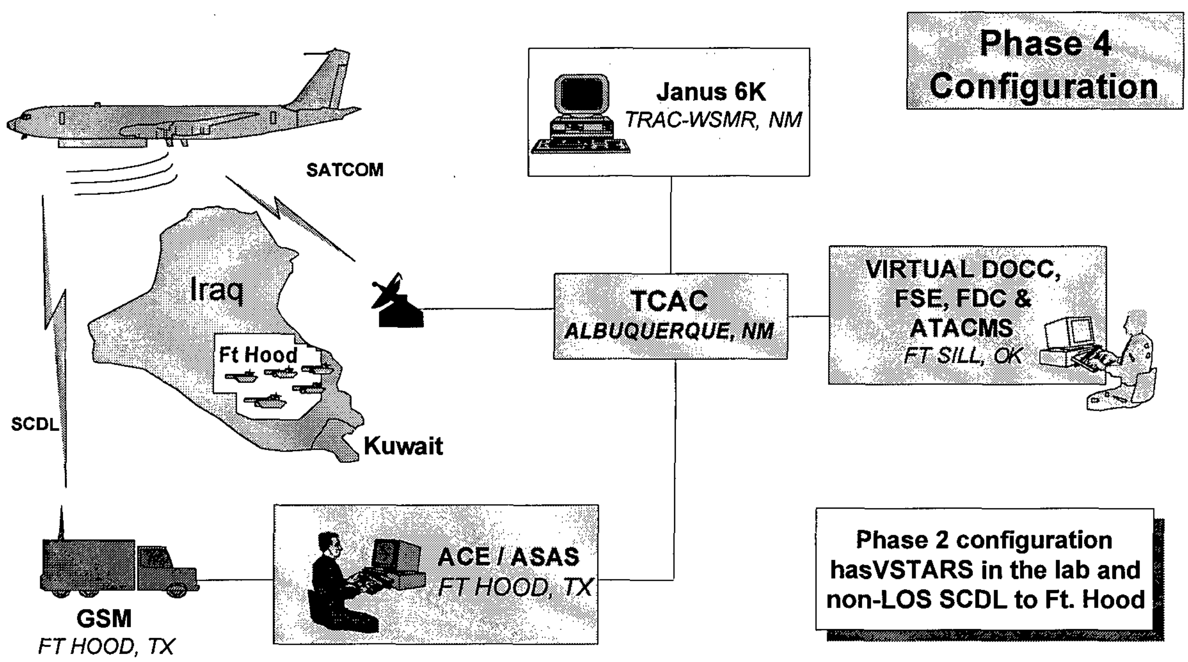

Figure 3. End-to-End Test Architecture

The ETE is a four-phased test. Phase 1 was largely developmental – constructing the various components necessary to executing later phases of testing. These components include a high fidelity emulation of the Joint STARS radar processes, called Virtual Surveillance Target Attack Radar System (VSTARS), which includes both moving target indicator and synthetic aperture radar modes of operation. Phase 2 links representative entities for the end-to-end process while the "system under test" is in a laboratory environment enabling JADS to explore the utility of ADS in the DT&E and early OT&E of a C4I system. Phase 3 hosts VSTARS on board the actual Joint STARS aircraft and performs final integration testing. Phase 4 is an actual live open air test with the aircraft airborne, with the environment augmented by ADS.

Electronic Warfare Test (Ref. 6)

JADS EW Test was chartered separately by OSD to examine the utility of ADS in EW T&E. To allow JADS to conduct a broad analysis of this domain and remain within very tight fiscal constraints, a "multi-vectored" approach is employed. JADS leveraged off the

U.S. DoD High Level Architecture (HLA) Engineering Prototype Federation for lessons learned in constructing and implementing a distributed architecture for EW T&E. At the bequest of DoD's CROSSBOW Committee, JADS directed the TSLA Study, which delineates how to link DoD's EW test facilities using the HLA. Third, JADS is participating with the U.S. Army in its Advanced Distributed Electronic Warfare System (ADEWS) test, a concept that provides EW effects on communications gear in the open air environment without the actual EW open air emissions. Fourth, JADS offers test agencies and program offices "comparison studies," where a traditional test of a system is compared with an ADS-enhanced test to identify potential benefits in test thoroughness, time and money. JADS Flag Officer Steering Committee directed that these studies be performed after the JTF has performed its self-protection jammer (SPJ) test.

SPJ Test (Ref. 7)

The SPJ test has been designed as a three-phased test focusing on the U.S. DoD EW test process, and utilizes the ALQ-131 as its "system under test." Phase 1 is a non-ADS test of the SPJ on an open air range (OAR), augmented with data obtained by testing the ALQ-131 in a hardware-in-the-loop facility. The purpose of this test is to establish a baseline of environment and performance data which will be used to develop the ADS test environment for the following phases and will be the basis for determining the validity of ADS test results. Phase 2 is a test of a high-fidelity real-time digital system model (DSM) of the ALQ-131 linked with hardware-in-the-loop terminal threats and a constructive model of an Integrated Air Defense System (IADS). The threat laydown from the OAR is replicated in the synthetic ADS environment and the ALQ-

131 will be flown, via a scripted flight profile developed from the actual OAR flights, through the IADS, engaging the high-fidelity terminal threats. Phase 3 is a test of the SPJ installed on an actual aircraft located in an Integrated System Test Facility (ISTF). The facility will be linked with hardware-in-the-loop threats and the constructive model of the IADS using the same threat laydown as the previous test and controlled by the same scripted flight profile. Figure 4 illustrates Phases 2 and 3 of the SPJ test.

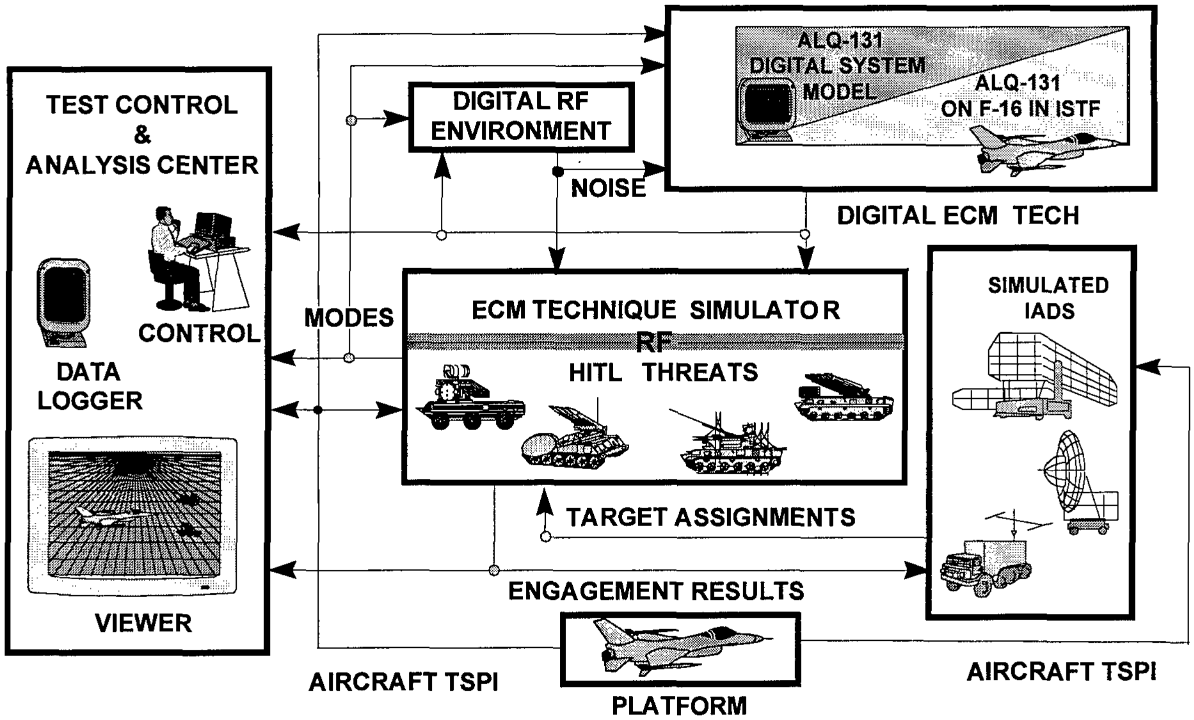

Figure 4. Self-Protection Jammer Phases 2 and 3

JADS JT&E Test Results

At the time of this writing, JADS has completed one phase of the ETE and both phases of SIT. As the first phase of ETE was largely developmental, this section will focus on SIT results. For a schedule of JADS test execution, refer to Figure 5).

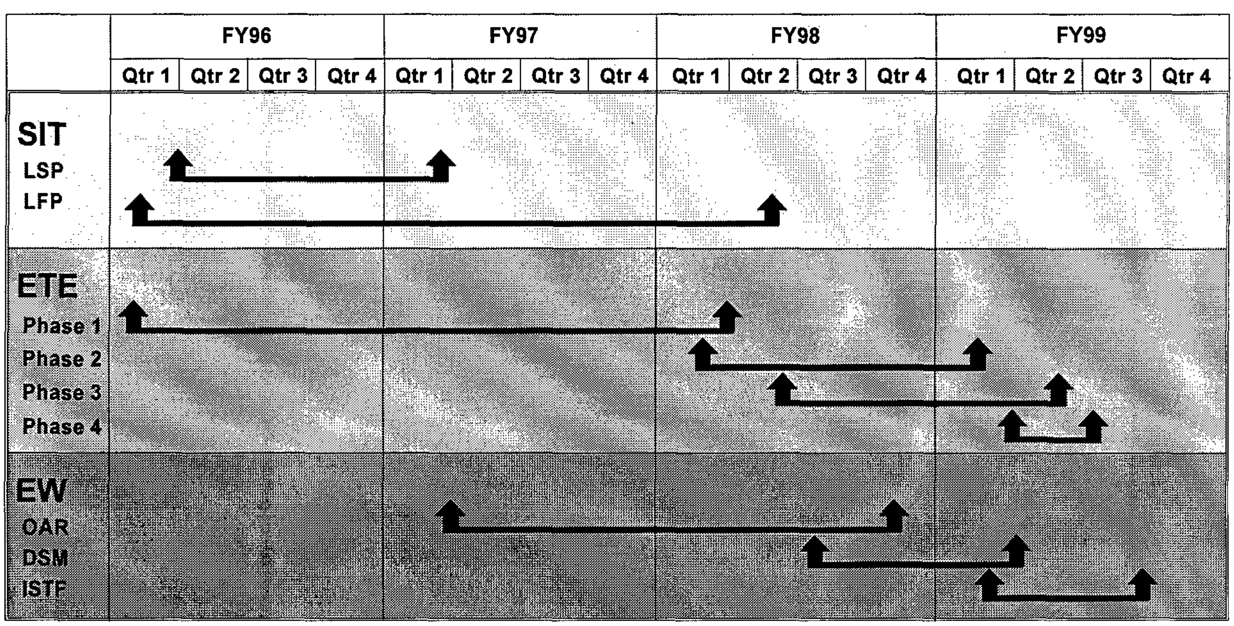

Figure 5. JADS Test Execution Schedule

Linked Simulators Phase Results (Ref. 8)

The key results from LSP testing were as follows:

- The simulation facilities were properly linked, and the missile flyouts were valid for the target representation in the Simulation Laboratory (SIMLAB). However, this target representation differed somewhat from the target data originating from the Weapon System Integration Center (WSIC).
- The manual method for replicating a given profile resulted in very good run-to-run reproducibility of the engagements.
- The average latency of all entity state data during the final mission were relatively small (<100 milliseconds from simulation to simulation) and consistent run-to-run. However, relatively large random latency variations were often observed which resulted in an uncertainty in the target location, as perceived in the SIMLAB.
- The ADS network provided ample bandwidth and no loss of connectivity during testing.
- There were no significant ADS-induced errors.
- The reliability of the long-haul network was very good, and the availability of the complete LSP ADS configuration was on the order of 85%.
- Test control procedures were refined throughout the preparation process and worked well during testing.

Live Fly Phase Results (Ref. 9)

The key results from LFP testing were as follows:

- The live aircraft were properly linked to the missile HWIL laboratory, and the Missile Laboratory (MISILAB) generated valid AMRAAM data during the engagement.
- Accurate time-space-position information (TSPI) solutions were generated by the TSPI Data Processor (TDP) to the order of one to three meters in position and one meter per second in velocity. This well exceeded MISILAB accuracy requirements.
- The shooter and target TSPI data were properly synchronized to each other and to the umbilical and data link messages for input to the MISILAB simulation.
- Latencies during testing were relatively stable and consistent, but fairly large. The total latency of the MISILAB simulation was about 3.1 seconds. This large value of latency was due to the processing and buffering of the TSPI data to produce accurate and smooth solutions and to the synchronization technique used.
- The ADS network provided ample bandwidth and no loss of connectivity during testing.
- There were no significant ADS-induced errors.
- Test control procedures worked well during testing with centralized test control exercised from the CCF.

System Integration Test Lessons Learned

LSP Lessons Learned

LSP lessons learned are documented in much detail in JADS LSP Final Report (Ref. 10) and are categorized in the general domains of technical and infrastructure lessons learned. What follows are some of the highlights.

LSP Technical Lessons Learned

- Accurate coordinate transformations are necessary. They must be verified and validated at each site and then revalidated during end-to-end testing as early as possible in the test phase.
- Quantitative validation has limitations. JADS intent was to quantitatively verify missile simulation performance against live fire data. However, as only one live fly event was available to support the process, a modified approach including both quantitative and qualitative methods was used, and successfully identified invalid results.
- Network interface units (NIUs) need improvement. NIUs are necessary if two nodes cannot communicate directly in a common language. They can be a major source of both errors and processing delays. Better direct user control of the content of the data and network communications is needed.
- Common ADS-related hardware and software is needed. In the LSP, it was difficult to get the ADS network to behave in a uniform fashion due to the many different types of interface hardware, communications equipment (routers), and interface software versions.
- Latency variations were significant. Processing delays were the primary culprit here.
- Time sources must be synchronized off the same time source and then must be validated at each test site prior to project operations to ensure accurate, synchronized time is precisely recorded at each test site.
- Special test equipment is needed for check-out and verification of the ADS architecture. Without this equipment, trial and error becomes the norm when (not if) problems crop up.

LSP Infrastructure Lessons Learned

- The requirements for an ADS test must be clearly defined early in the test planning phase. This includes user requirements, support agency's stated actions, and operations security requirements. Planning and coordination details will be much more involved than in a traditional, non-ADS test.
- Get "system under test" experts involved from the beginning.
- Test communications requirements must be addressed early in the test planning phase. This is necessary to ensure effective communications during the test. Also, a linked test should have multiple (more than two) communications nets with easy, selectable access to all the nets from multiple locations within the site. Finally, the capability for secure video teleconferencing pays big dividends during planning, coordination, and post-test debriefs.
- A stepped build-up approach should be used. First, a systematic check-out of the stand-alone simulators (live, virtual or constructive) is needed. Next, direct (non-DIS) links should be used during test build-up. Finally, structured testing of the network must be performed prior to, and

independent of, the linked testing times and the simulation laboratories to validate transmission/reception rates, bandwidth utilization, latency, data transmission and reception, etc., prior to commencing project test periods.

- Linking of facilities using ADS can require significant facility interface hardware and software development. ADS implementation is not "plug and play," at least for some time.
- Local (on-site) test monitoring/control should be used prior to remote test monitoring/control.
- Tight control of the aircrew is not desirable. Give them the critical parameters and switchology to meet the test objectives and allow them to make tactical decisions, fly the "aircraft," operate the weapon system, etc.
- Additional time is needed before the beginning and after the end of each testing period. One hour is recommended for set-up, and two hours at the end for data logging, data archiving, data transfer, and laboratory reclassification.
- Briefings are needed before and after each mission.
- Effective data management is needed, as ADS can generate mountains of data. A comprehensive plan will clearly identify the data to be collected at each site, on-site processing of the data, and data to be transferred to the analysis center.
- Adequate time must be allowed for data analysis between test events. Analysis procedures should be rehearsed to better understand the amount of time needed for this analysis.
- Configuration control is essential. This one obvious area was one of great challenge considering the many sites involved and the multiple uses of each site.

LFP Lessons Learned

LFP lessons learned are documented in much detail in JADS LSP Final Report (Ref. 11) and are also categorized in the general domains of technical and infrastructure lessons learned. Some of the highlights are listed below.

LFP Technical Lessons Learned

- As in the LSP, a major lesson learned is that stand-alone simulation facilities (for live, virtual or constructive entities) can require significant modifications before effective linking is possible.
- Additionally, linking may require special purpose interfaces so as to accept inputs in real time. Development of such units must be factored into test planning.
- Key interfaces need realistic integration testing. Replaying data from a recorded mission worked well in most cases (and was most cost effective); however, some integration testing required a live mission.
- Early definition of network requirements was very advantageous. This was a major lesson from LSP that JADS took advantage of.

LFP Instrumentation Lessons Learned

- Changes and upgrades to aircraft instrumentation delayed development. Specially instrumented aircraft were required to support the LFP flights. Due to the small number of such

aircraft, the LFP schedule was very sensitive to periodic aircraft phase inspections, software upgrades, and higher priority missions.

- Merging several TSPI sources was advantageous. Real-time aircraft inertial navigation system (INS) and global positioning satellite (GPS) data were combined to calculate more accurate kinematic estimates. When combined with the ground radars, solutions of one to three meters in position and one meter per second in velocity were achieved.
- A strong program manager or system integrator is needed to oversee facility development, due to the difficulty in coordinating several diverse facilities to successfully integrate an ADS-linked configuration.
- Use risk reduction tests for integration. A building block approach was used successfully to check out interfaces at the lowest level, then one or two resources at a time were added to integrate the linked configuration. These risk reduction tests were also useful for developing analytical tools.
- Several subnetworks should be used for voice communications. Three voice communications networks were needed to support more than 30 people at various locations, and a fourth network could have further aided decision making.
- Two-dimensional displays were needed at each node; they greatly enhanced the situational awareness of the participants.
- Existing range procedures had to be modified for ADS. The existing test procedures were only written for individual facilities, so a new combined checklist was created for ADS applications.
- Laboratory replays served as an excellent method of test rehearsal.

Other Topics for Consideration

Threat Simulator Linking Activities (TSLA) Study (Ref. 12)

TSLA is a study chartered by the U.S. DoD's CROSSBOW Committee and directed by the JADS JTF. The TSLA study provides an ADS Capabilities Assessment Report which describes the utility of ADS in the context of the evolutionary acquisition process interwoven with T&E. At each phase of the acquisition process, the conventional and ADS methodologies are applied. For each phase, the necessary test facilities are delineated and the differences in test capabilities noted. Test facility requirements are addressed for SPJs, stand-off jammers, and integrated avionics. As the test facility requirements are reviewed, any improvements needed to meet the requirements of the electronic combat test process are noted. Some of these improvements are needed without regard for ADS. In other cases, the improvements are needed only to support ADS. Comparisons of capabilities, with and without ADS, are discussed. General assessments of the cost impact of ADS are also discussed.

Requirements for and the impact of latency are also discussed. Latency will be present. Depending on the network topology, physical communication infrastructure, and network management methods, it may be possible to achieve a tolerable latency for most applications. Latency remains the greatest technological risk to the successful use of ADS in EW T&E.

Considerations for the T&E Professional

Although JADS still has another year of ADS testing ahead of it, there are several overall considerations which have become evident. What follows are some highlights, as recently briefed to JADS Flag Officer Steering Committee (Ref. 13), and adopted into a pamphlet entitled "Emerging Findings from JADS."

- ADS allows one to link live, virtual, and constructive players based on need. ADS does not mean linking together several constructive simulations to make a bigger, more complex model. Rather, it means blending live, virtual and constructive players to give the user the right mix of fidelity and realism to meet specific needs.
- Distribution is not a function of distance. Latency is a function of processing and transmission, and processing latency dominates. Transmission latencies are predictable and relatively well behaved. Processing latencies can be problematic, though, and require a thorough understanding of the individual sites and the ADS architecture. This holds true whether the network covers a continent or multiple nodes at a single location.
- Validating against live data is problematic. Problems include the quality of the live data and the lack of data availability.
- Data collection is different from traditional T&E and training. Generally speaking, an ADS environment is easier to instrument than the traditional live test environment and provides more trials per unit of time. The end result is that analysts can get inundated with data. In addition, ADS testing requires additional data to be collected on the performance of the networks linking your sites.
- ADS cost benefits are best realized over the entire system life cycle. JADS has performed some cost benefit analyses comparing traditional test approaches to ones utilizing ADS. In many cases, it appears as if ADS could save time and money (as well as allowing a more rigorous test) in just the test phase of a development program. However, the full benefits of using ADS would be realized over all the phases of the acquisition cycle, from requirements development to training and sustainment. This supports the concepts advocated in both simulation based acquisition (SBA) and Simulation, Testing and Evaluation Program (STEP).
- ADS allows one to test "differently." Adding ADS to a traditional test approach provides only a fraction of the value ADS can bring to bear. To realize the full capabilities of this enabling technology, one will construct a test event fundamentally differently than its traditional forefather.
- To a certain extent, latency is manageable. The ADS architectural design is the most determining factor of latency. The tester must approach network design from a requirements viewpoint. Based on what the tester is trying to accomplish, an architecture can usually be designed which balances the types of participating assets, fidelity requirements, and tolerable latency.
- The effect of latency is dependent on the players involved. Latency is a factor when the tester is trying to generate closed-loop interactions. Again, the tester must approach the test from a requirements viewpoint in determining whether an ADS architecture can provide the interactions needed for the test event.

Conclusions

JADS has been chartered to determine the truth as to where ADS is, or is not, a feasible tool for T&E. JADS JT&E testing is well underway, and the early evidence is that ADS can bring many benefits to the table. However, one must be fully aware of the inherent limitations of the technology. Also, one would be well advised to learn from those who have practical experience in using ADS in the T&E arena. Distributed simulation is certainly not a panacea that will solve all of the problems and meet all of the requirements. However, it does appear to be a powerful tool, if used appropriately and intelligently, and should be considered in balance with other methodologies when developing a T&E program.

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Acronyms

Following are acronyms found in this paper's figures and not defined in the body of the paper.

Figure 1
A/C - Aircraft
IR - Infrared
MSL - Missile
SMS - Stores Management System
TGT - Target

Figure 2
AASI - Aircraft Avionics Simulation Interface
ECM - Electronic Countermeasures
RDL - Rear Data Link
UMB - Umbilical
TM - Telemetry

Figure 3
ACE - Analysis and Control Element
ASAS - All-Source Analysis System
ATACMS - Army Tactical Missile System
DOCC - Deep Operation Coordination Center
FDC - Fire Direction System
FSE - Fire Support Element
GSM - Ground Station Module
LOS - Line of Sight
OK - Oklahoma
SATCOM - Satellite Communications
SCDL - Surveillance Control Data Link
TRAC - U.S. Army Training and Doctrine Command Analysis Center
WSMR - White Sands Missile Range

Figure 4
ECM - Electronic Countermeasures
IADS - Integrated Air Defense System
RF - Radio Frequency
TECH - Technique

Figure 5
FY - Fiscal Year
Qtr - Quarter

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